COMPASS++/AMBER
Outcome of the 2020 update of the European Strategy for Particle Physics

COMPASS++
AMBER

Perceiving the Emergence of Hadron Mass through AMBER@CERN, **CERN, e-conference, Aug. 6-7 2020**

Outline

1. Intro/LoI COMPASS++/AMBER
2. COMPASS++/AMBER Physics case:
   - Emergence of the hadronic mass (meson structure)
   - Proton spin structure
3. Physics Beyond Colliders at CERN initiative – a part of the European Strategy for Particle Physics Update process
4. Outcome of the PBC as reported to the final ESPP Granada May 2019 open meeting
6. Outcome of the ESPP update
7. Summary

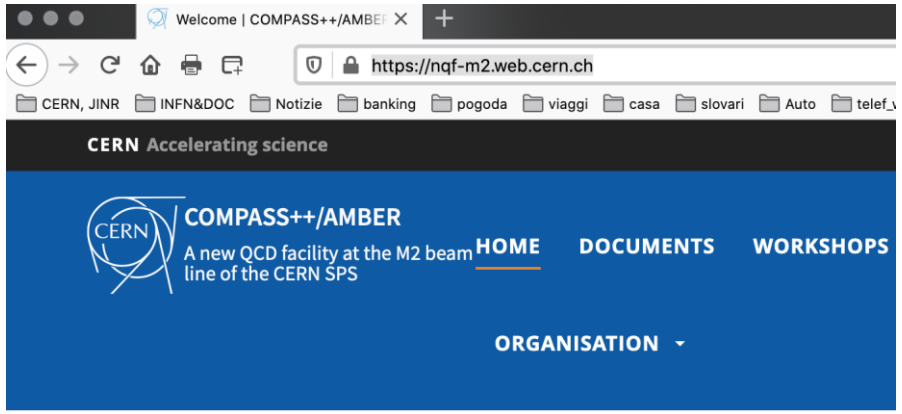
COMPASS++/AMBER
approximately 10 years-long effort, LoI is submitted in Jan. 2019

COMPASS++
AMBER

We have started to work on physics program of possible COMPASS successor ~ 10 years ago,

A Number of Workshops has been organized, for detail see COMPASS++/AMBER web page:

https://nqf-m2.web.cern.ch/



Welcome

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–003
SPSC-I-250
January 25, 2019

http://arxiv.org/abs/1808.00848

Apparatus for Meson and Baryon Experimental Research
> 270 authors

[hep-ex] 25 Jan 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++†/AMBER‡

B. Adams[13,12], C.A. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[14], M.G. Alexeev[41], A. Amoroso[41,42],

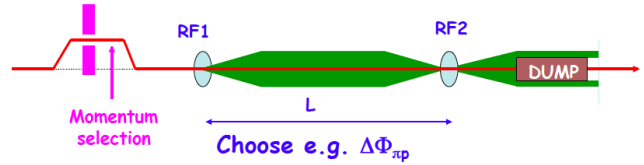
COMPASS++/AMBER
A New QCD Facility at CERN SPS M2 beam line

COMPASS++ AMBER

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pressure H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2 \cdot 10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	$\overline{p}$ production cross section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	liquid helium target
$\overline{p}$-induced spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectrometer: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisa-bility & pion life time	~100	$5 \cdot 10^6$	> 10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	$\geq$ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

Table 2: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.

Conventional muon/hadron M2 beams



$\Delta\Phi = 2\pi\ (L\ f\ /\ c)\ (\beta_1^{-1} - \beta_2^{-1})$ with $\beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$

COMPASS++/AMBER PHASE-1

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AMBER

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PHASE-1

Conventional hadron and muon beams

2022 ➔ 2025 and beyond

PHASE-2

Conventional and RF-separated Hadron/Hadron and muon beam

2026 and beyond

Two bearing columns of the COMPASS++/AMBER

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There are two bearing columns of the facility:

1. **The issue of the emergence of the hadron mass**
2. **Proton spin (largely addressed by COMPASS)**

FIRST, EHM:

How does the all visible matter in the universe come about and what defines its mass scale?

Unfortunately, the Higgs-boson discovery (even if extremely important) does NOT help to answer this question:

- ✓ The Higgs-boson mechanism produces only a small fraction of all visible mass
- ✓ The Higgs-generated mass scales explain neither the "huge" proton mass nor the 'nearly-masslessness' of the pion

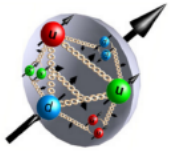
Pion

- $M_\pi \sim 140$MeV
- Spin 0
- 2 light valence quarks

Kaon

- $M_K \sim 490$MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks

Proton



- $M_p \sim 940$MeV
- Spin 1/2
- 3 light valence quarks

Higgs generated masses of the valence quarks:

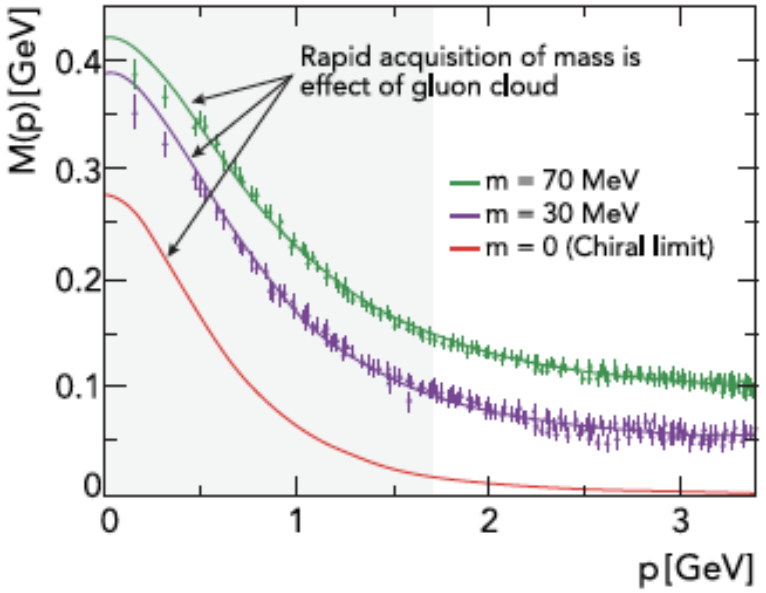
$M_{(u+d)} \sim 7$ MeV $M_{(u+s)} \sim 100$ MeV $M_{(u+u+d)} \sim 10$ MeV

As Higgs mechanism produces a few percent of visible mass, thus the mass scale is defined by QCD mechanisms

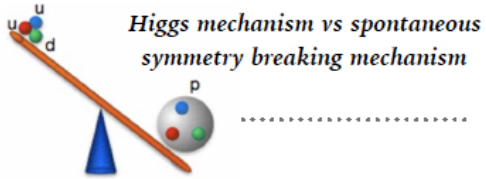
EHM
(mass budget in proton, different QCD mechanism for Nambu-Goldstone bosons)

COMPASS++ AMBER

Dressed-quark mass function M(p)



The proton mass in the chiral limit is close to its nominal mass, as quark «gain» a mass evolving in to constituent one as its momentum became smaller.

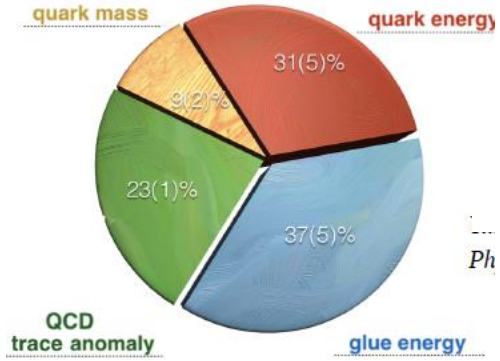


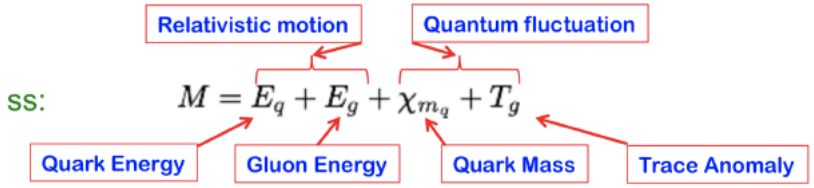
It is very different for pion and kaon (lightest Nambu-Goldstone modes) as they are massles in the chiral limit by definition.

Does this mean that their gluon content is equally small and different from the proton once? ➔ Must Study PDFs

One of the possible proton mass decomposition (calculation on lattice)

Yi-Bo Yong et al.,
Phys.Rev.Lett. 121 (2018) no.21, 212001





COMPASS++/AMBER – being a new proposal was examined in the period 2016-2020 within Physics Beyond Colliders initiative (CERN) I

The goal of the PBC initiative (on request of CERN DG F. Gianotti) was to make a review of complete set of a newly proposed non-collider experiments at CERN. Those proposals were in a different stage of reparation and were belonging to a different fields of physics: QCD physics, nuclear physics, search for dark matter etc. COMPASS++/AMBER was represented in 2 working groups (QCD Physics and Extracted Beams) by O.Denisov and G.Mallot (substituted by J.Friedrich)

The final goal of the PBC initiative was to submit a summary review document as input to the 2020 European Strategy for Particle Physics update process. The final public ESPP update event took place in Granada in May 2019. The ESPP update process is restarted once in 7 years.

QCD @ Physics Beyond Collider

Strong-interaction physics at the existing CERN pre-accelerator complex

Gunar Schnell

ESPP Update — Open Symposium Granada May 2019

CERN-PBC-REPORT-2018-008

Physics Beyond Colliders
QCD Working Group Report

A. Dainese[1], M. Diehl[2,*], P. Di Nezza[3], J. Friedrich[4], M. Gaździcki[5,6] G. Graziani[7], C. Hadjidakis[8], J. Jäckel[9], M. Lamont[10] J. P. Lansberg[8], A. Magnon[10], G. Mallot[10], F. Martinez Vidal[11], L. M. Massacrier[8], L. Nemenov[12], N. Neri[13], J. M. Pawlowski[9,*], S. M. Pulawski[14], J. Schacher[15], G. Schnell[16,*], A. Stocchi[17], G. L. Usai[18], C. Vallée[19], G. Venanzoni[20]

Abstract: This report summarises the main findings of the QCD Working Group in the CERN Physics Beyond Colliders Study.

- summary report of QCD studies within the “Physics Beyond Colliders” initiative
- selected results relevant for pre-accelerator complex:
  - COMPASS++ / AMBER
  - DIRAC++
  - MUonE

COMPASS++/AMBER – being a new proposal was examined in the period 2016-2020 within Physics Beyond Colliders initiative (CERN) II

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Proposals and studies within PBC-QCD

- experiments at SPS and fixed-target installations at LHC
- cover a broad range of topics in QCD
  - ★ parton densities, proton and nuclear structure
  - ★ heavy-ion physics
  - ★ low-energy dynamics
  - ★ measurements for other fields of HEP: (g-2)μ, cosmic rays, neutrinos

☛ J.-P. Lansberg ☛ T. Galatyuk

	LHC FT gas				LHC FT crystals	COMPASS++	MUonE	NA61++	NA60++	DIRAC++
	ALICE	LHCb	LHCSpin	AFTER@LHC						
proton PDFs	×	×		×						
nuclear PDFs	×	×		×		×				
spin physics	×		×	×		×				
meson PDFs						×				
heavy ion physics	×			×				×	×	
elast. μ scattering						×	×			
chiral dynamics						×				×
magnet. moments					×					
spectroscopy						×				
measurements for cosmic rays and neutrino physics	×	×		×		×		×		

Table 1. Schematic overview of the physics topics addressed by the studies presented in the QCD working group.

AMBER (aka COMPASS++)

- a comprehensive physics program suggested to run at the M2 beam line
- includes measurements with
  - ✦ conventional muon and hadron beams
  - ✦ upgraded RF-separated hadron beams
- spanning several LHC runs
- RF-separated beams would basically eliminate the high-E/high-I muon beam (unique in the world!)
- not all topics to be covered here!

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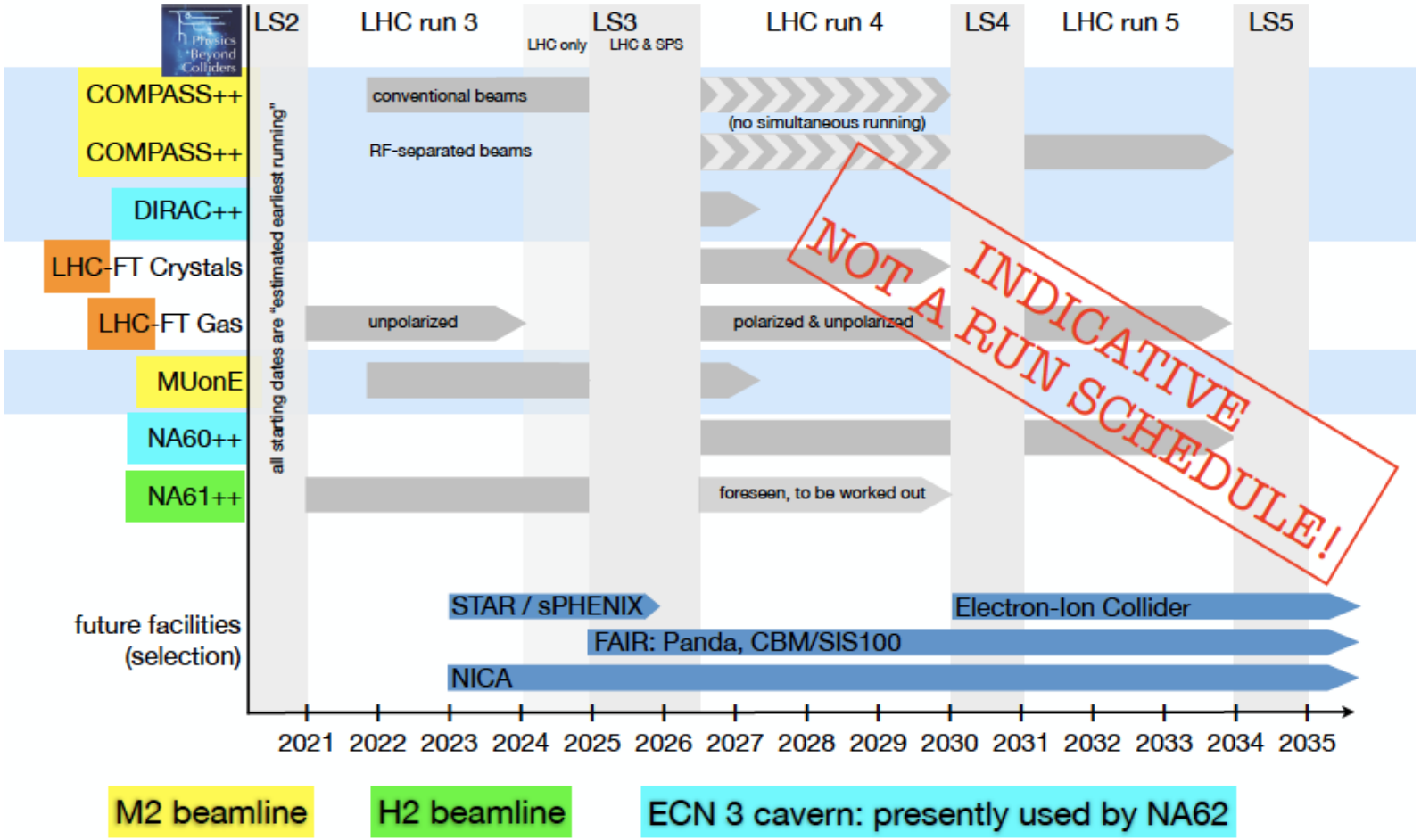
[AMBER, arXiv:1808.00848]

COMPASS++/AMBER – being a new proposal was examined in the period 2016-2020 within Physics Beyond Colliders initiative (CERN) III

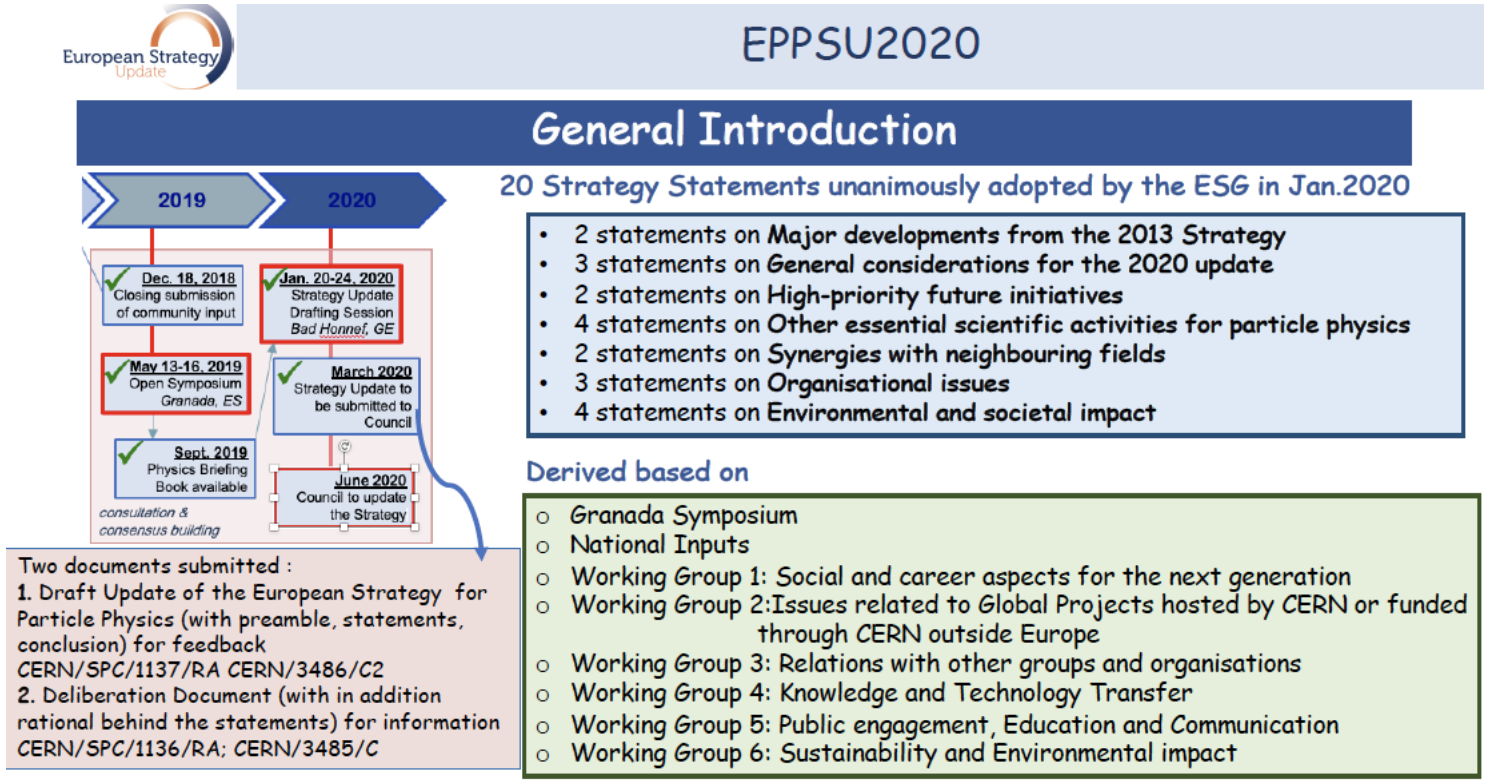
time lines and (possible!) locations of PBC-QCD projects



COMPASS++/AMBER – ESPP update outcome I

ESPP update document became public (after some delay because of the COVID-19) in June 2020.
A summary presentation of the outcome of the update process (valid for the time period 2021-2027) was reported to the CERN community (open CERN Council session) by Halina Abramowicz on June 19th 2020.

The main part of the document and talk was dedicated to the the next large collider project of CERN, but we as QCD (or hadron physics community) got what we wanted.



COMPASS++/AMBER – ESPP update outcome II

COMPASS++ AMBER

The most important output of the ESPP 2020 update ➔ COMPASS++/AMBER is on the list of future facilities in the period 2021-2030.

European Strategy Update

2020 Strategy Update

4. Other essential scientific activities for particle physics

Summary of "Physics Beyond Colliders" (PBC) study – aimed at exploring opportunities offered by the accelerator infrastructure of CERN and European research centres

			2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
		SPS	LS2						LS3						LS4				
		LHC	LS2		Run 3				LS3				Run 4		LS4				
North Area	NA64-electron	Operational	LS2		Data Taking										LS4				
	NA64-mu	< 1 MCHF	Studies		Test	Pilot	Phase 1												
	NA61/Shine	< 2 MCHF	Detector upgrade		Data Taking					Data Taking									
	MUonE	< 2 MCHF	Preparation		Pilot	Run 1	Data Taking												
	NA62-beamdump	< 1 MCHF	Studies		1e18 PoT in Run 3														
	KLEVER	~40 MCHF	EoI/proposal		R&D/Construction				Installation	Data Taking									
	COMPASS++	~10 MCHF	Studies/proposal		Phase1 Data Taking/Studies/R&D				Installation	Data Taking									

This statement does not mean an approval, but invitation to go ahead with the project and submit a proposal on a long term plans, no show stopper

COMPASS++/AMBER – ESPP update outcome III

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- Physics Beyond Colliders study identified many high impact options with modest investment
- Larger scale new facilities such a the Beam Dump Facility, and later LHeC option at CERN, difficult to resource within the CERN budget, considering the other recommendations of this Strategy
- Improvements in the knowledge of the proton structure needed to fully exploit the potential of present and future hadron colliders - added value from fixed target experiments and from Electron Ion Collider (CDO) in BNL

accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. *Experiments in such diverse areas that offer potential high-impact particle physics*

European Strategy Update

2020 Strategy Statements

5. Synergies with neighbouring fields

Particle and Nuclear Physics
- The synergies are driven by the ambition to achieve first-principle understanding of strong dynamics based on QCD
- They share similar experimental tools

Deliberation Document on the 2020 update of the European Strategy for Particle Physics:
Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board.

COMPASS++/AMBER – ESPP update outcome IV
+ additional input from CERN Research Director Eckhard Elsen

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1. COMPASS++/AMBER is on the list of future facilities at CERN, as stated by ESPP 2020 Update process
2. Importance of QCD physics is recognized
3. Complementarity with respect to EIC underlined
4. The only possible large scale “competitor” which might cause a delay for C++/AMBER (Beam Dump facility aka SHIP experiment) is turned down/postponed for the next ESPP review process
5. The idea of new (i.e. RF separated) hadron beams found a support and interest in the SPSC
6. We were encouraged to go ahead with our plans and submit Phase-2 Proposal in a shortest possible time (according to our plans we will submit is in the end of 2020, beginning of 2021)

COMPASS++/AMBER – Proposal Phase-1

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–022
SPSC-P-360
September 30, 2019

51 institutions, ~260 authors,
19 new institutions with respect to COMPASS
(USA, Germany, Italy, Russia etc.)

Proposal for Measurements at the M2 beam line of the CERN SPS

– Phase-1 –

COMPASS++*/AMBER†

B. Adams[14,13], C.A. Aidala[1], G.D. Alexeev[15], M.G. Alexeev[42,43], A. Amoroso[42,43], V. Andrieux[45,20],

We had two session of questions-answers with our SPSC referees, which results in ~100 page long document. The review process is till ongoing, we still have to address few question circulated to us after April 2020 meeting of SPSC.

VERY IMPORTANT: we receive for the first time very positive statement from the April SPSC meeting:

The physics potential of 150d mu-p elastic scattering and of a hadron-beam program for measuring the anti-p production cross-section in p-He collision as well as for pion-induced Drell-Yan and charmonium production have been recognized.

Summary

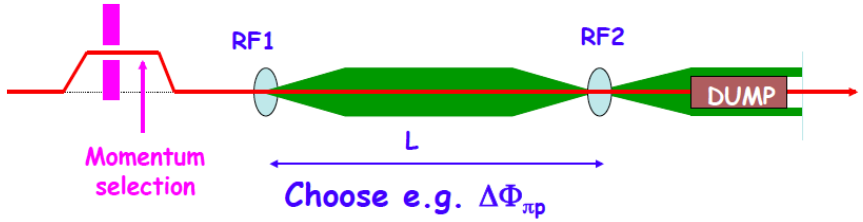
- Pion and Kaon structure and Emergence of Hadron Mass study is a major goal of the whole COMPASS++/AMBER enterprise

- Huge work which has been done by us in a framework of PBC and ESPP update brought us positive and important results: COMPASS++/AMBER facility is on the list of long term CERN fix target programs

- We are going in full swing with preparation of the Phase-2 proposal to be submitted at the end of 2020/beginning of 2021.

BACK UP

RF separated antiproton/kaon beam – a missing ingredient in the spin/mass crises resolving



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"Normal" h^- beam composition:
~97% (π) ~2.5%(K) ~0.5% (pbar)

Assumptions:

– 8×10^7 antiprotons for 10^{13} ppp (10 seconds) (optimistic estimate by Lau Gatignon);
– we assume here 4×10^{13} protons.

Antiprotons RF separated beam: 3.2×10^7 /s - Gain is a factor of 50 compared to the standard h^- beam for Drell-Yan experiment (~1% of h^- beam 6×10^7 /s dominated by π^-)

Using the same assumption for RF separated kaon beam, possible kaon beam intensity is 8×10^6 /s - Gain is a factor of 80 compared to to the standard "spectroscopy" h^- beam

High intensity RF separated beam will provide unique opportunities for Hadron Spectroscopy, Drell-Yan physics, Prompt Photon production etc.

COMPASS++/AMBER – Phase - 1
Interactions with SPSC I

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SPSC stays for "SPS and PS Experiments Committee"
The committee was created at the end of 1989 to replace the SPSC and PSCC Committees. The mandate of the committee is to referee the requests from the experimental teams on the basis of their physics interest and of the availability of the accelerators. It meets 4 times a year. The SPSC recommendations are sent to the Research Board, which takes the decisions.

The Phase-1 Proposal was submitted to the SPSC in the end of September 2019, it was discussed at the SPSC meetings in October 2019, January and April 2020.

We had two session of questions-answers with our SPSC referees, which results in ~100 page long document. The review process is till ongoing, we still have to address few question circulated to us after April 2020 meeting of SPSC.

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COMPASS++/AMBER – Phase - 2
input from the CERN authorities (RD E.Elsen)

In May we had a first very positive input on COMPASS++/AMBER Phase-2 (physics with RF separated kaon/antiproton beams mostly) from CERN Authorities (RD E.Elsen)

- The idea of new (i.e. RF separated) hadron beams found a support and interest in the SPSC

- The proposal is not competing or in any case might not be conditioned by the decision on new BeamDump facility construction in the North Area (SHIP experiment etc.)

- We were encouraged to go ahead with our plans and submit Phase-2 Proposal in a shortest possible time (according to our plans we will submit is in the end of 2020, beginning of 2021)

Thus we will proceed in full swing with a preparation of the AMBER Phase-2 Proposal, major part of it dedicated to the pion/kaon structure study